Prospects for Future Type Ia Supernova Cosmology

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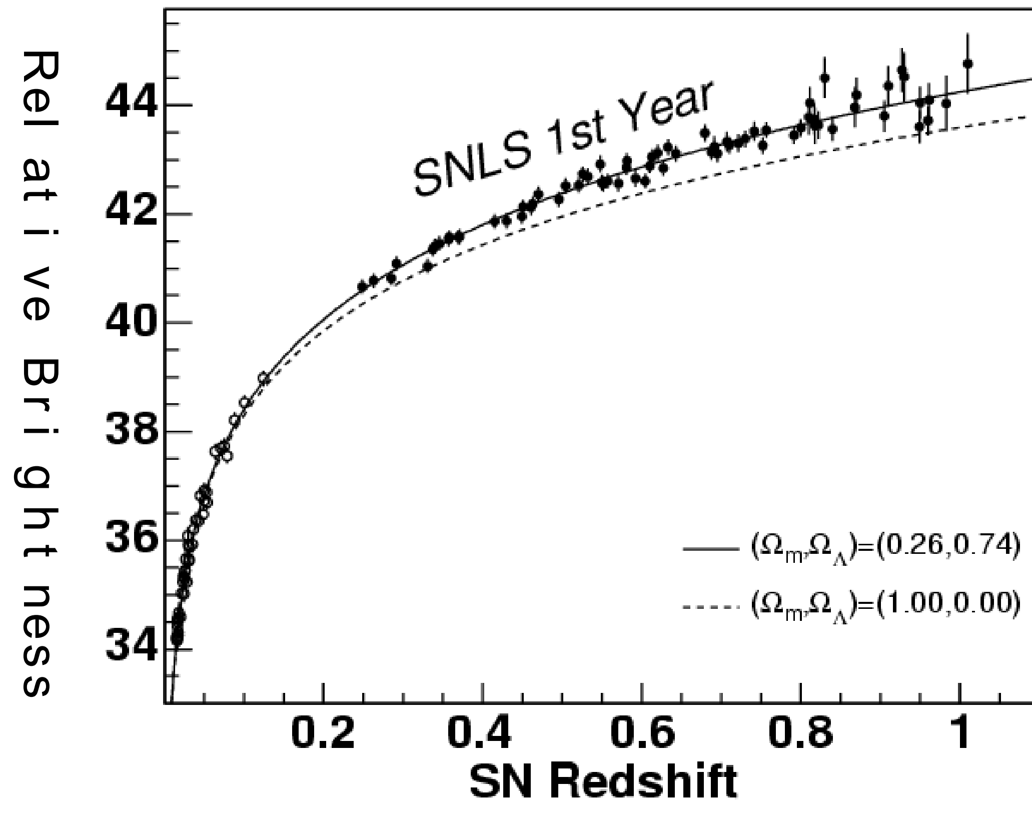
Supernova Cosmology Primer

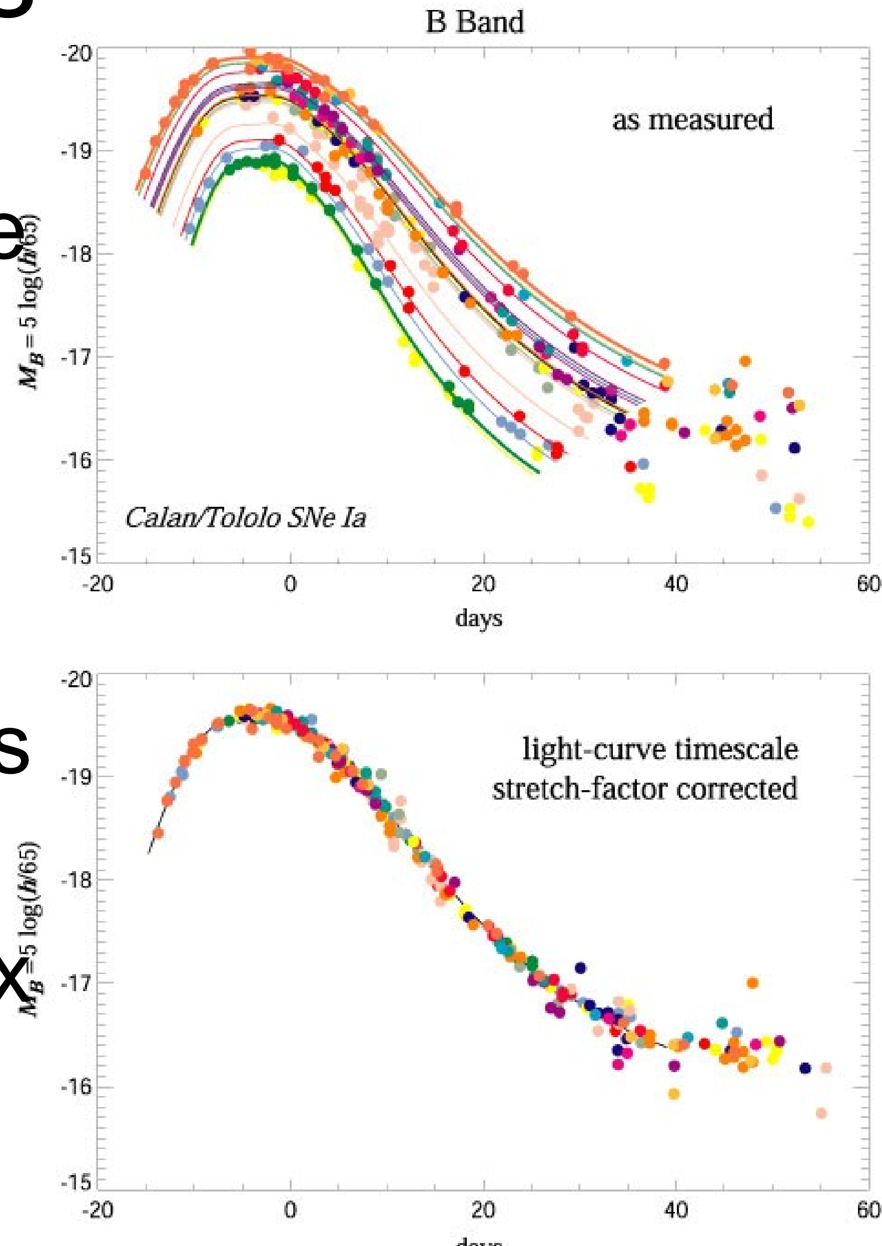
- Type Ia supernovae have uniform luminosity at peak brightness
- Relative brightnesses measure relative distances
- The SN Ia Hubble diagram (redshift vs. brightness) maps the expansion history of the Universe



Astier et al. (2006)

Type Ia Supernovae As Standard Candles

- After correction for foreground dust supernovae have peak-magnitude dispersion of ~0.3 mag
- After correction for light-curve shape supernovae become “calibrated” candles with ~0.15 mag dispersion
- Required data: temporal flux evolution in different wavelengths



Kim, *et al.* (1997)

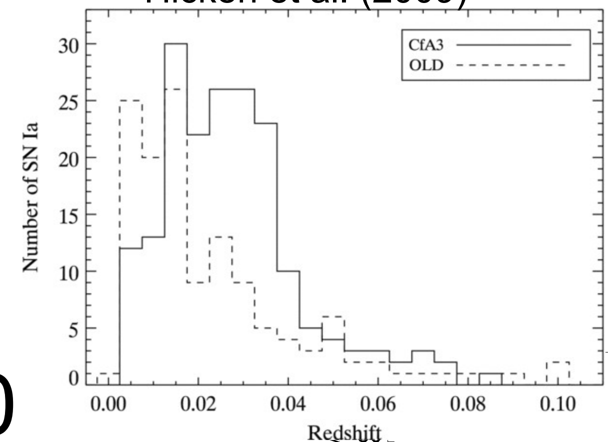
SN Ia Datasets Today

- Current cosmology analysis draws from a hodgepodge of data (Kessler et al. 2009, Hicken et al. 2009, Amunallah et al. 2009)
  - z<~0.1
    - 1-m photometry, 2-m spectroscopy
    - SNFactory, KAIT, CfA
  - z~0.25
    - 2.5-m photometry, >=4-m spectroscopy
    - SDSS
  - z~0.5
    - 4-m photometry, >=8-m spectroscopy
    - Essence, SNLS, SCP
  - z>0.8
    - HST photometry, >10m and HST spectroscopy
    - PANS, SCP
  - CSP
    - YJHK z<0.1, YJ z<0.7

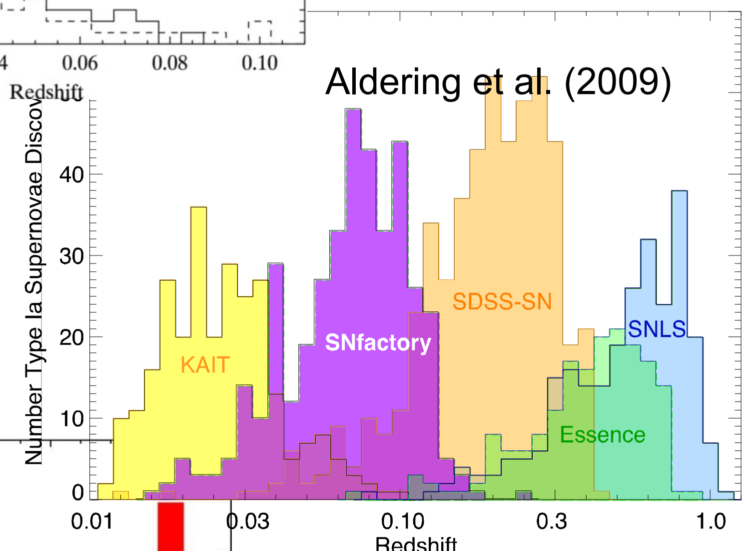
Numbers and Redshift Distribution

- Nearby >300
- SDSS ~100
- ESSENCE+SNLS ~140
- HST ~35

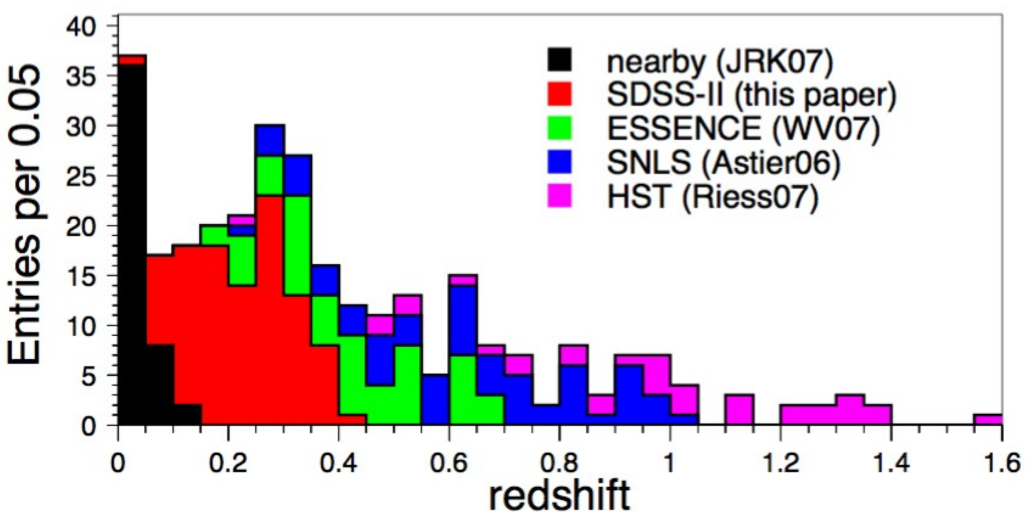
Hicken et al. (2009)

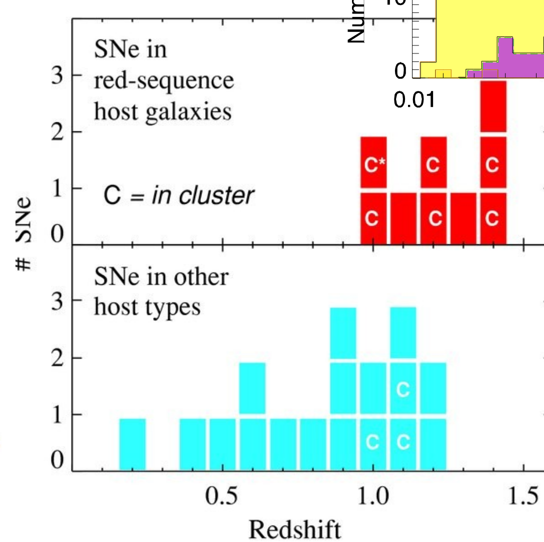


Aldering et al. (2009)



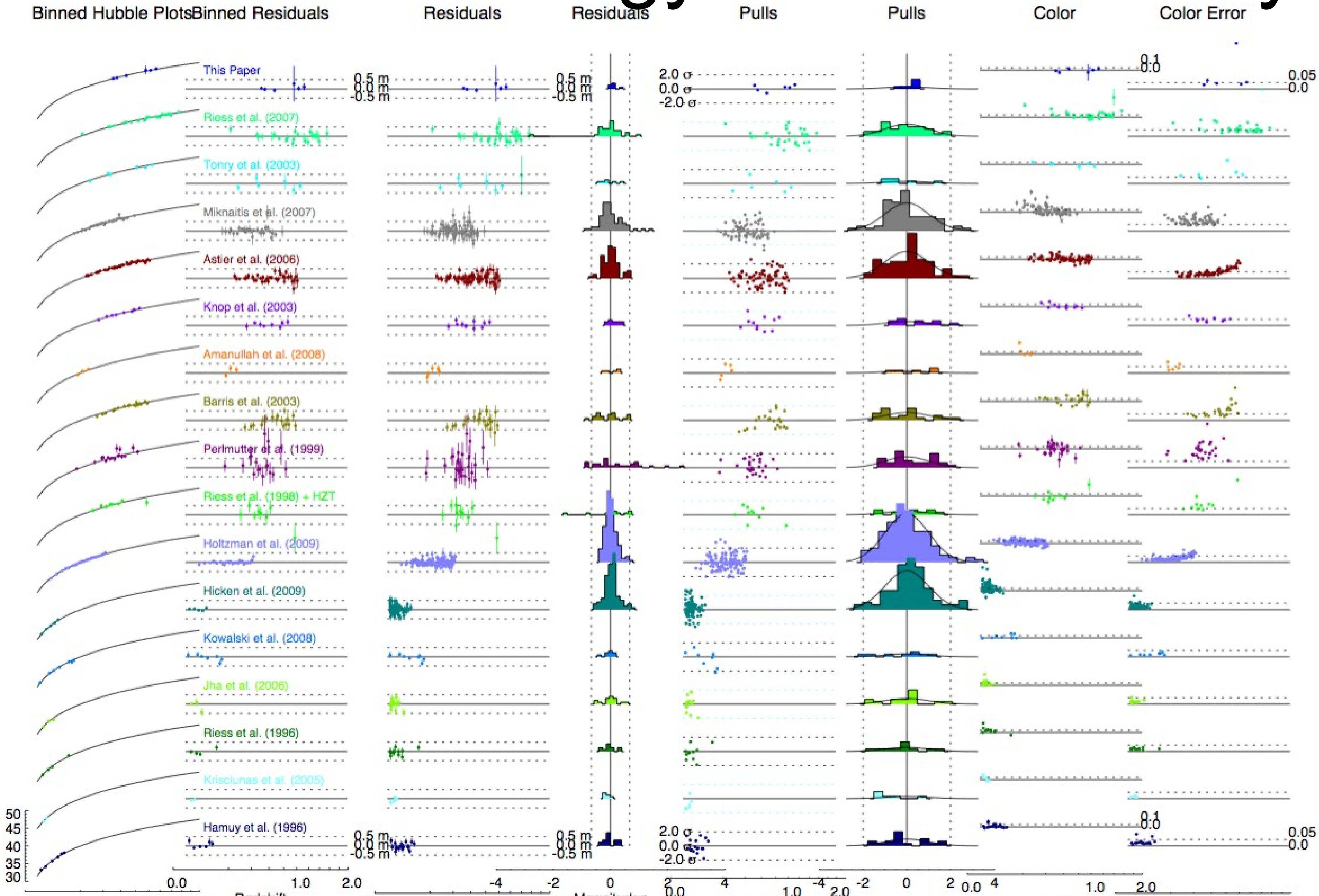
Kessler et al. (2009)





Dawson et al. (2009)

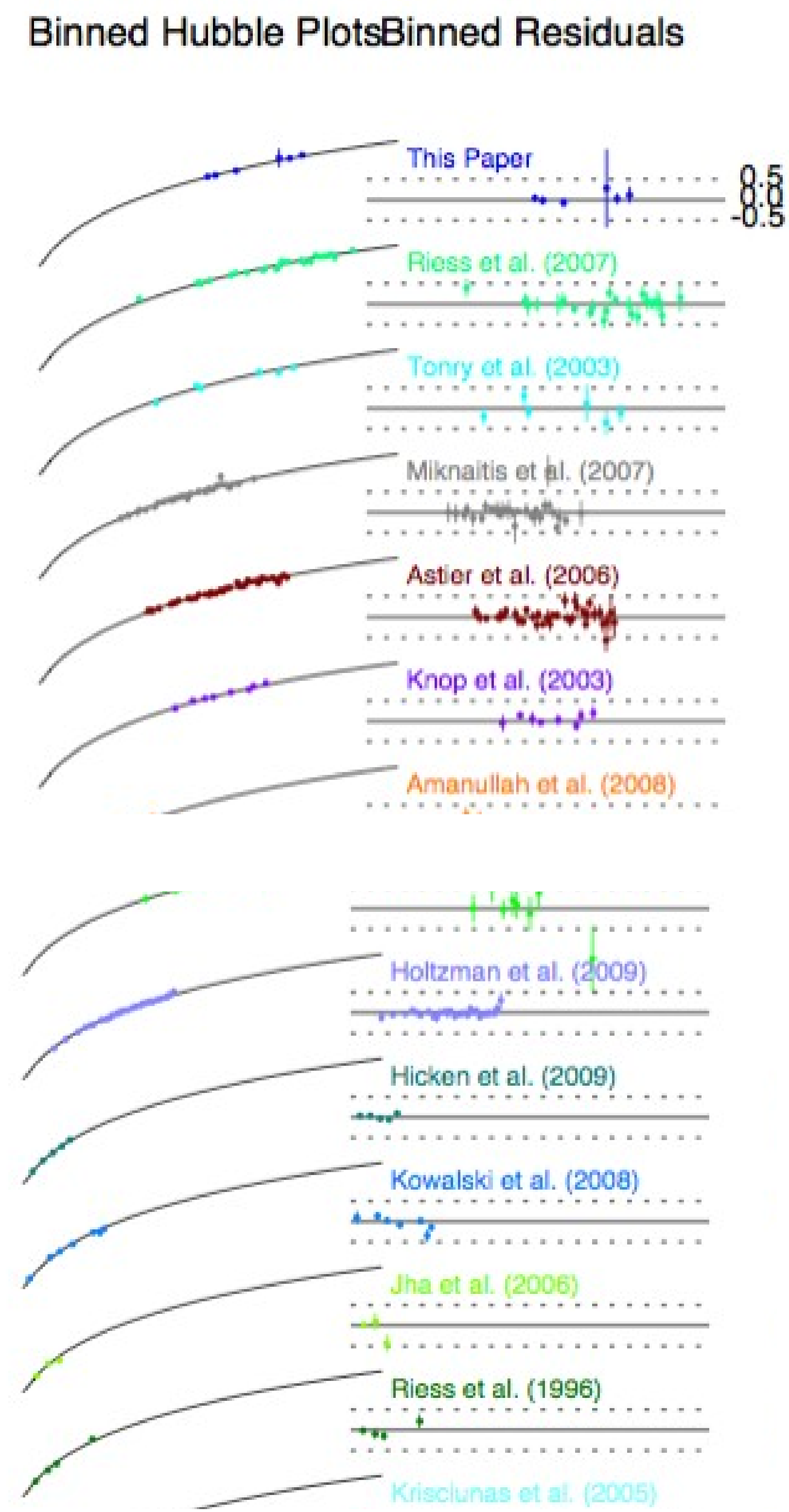
SN Ia Cosmology Datasets Today



Amanullah et al. (accepted)

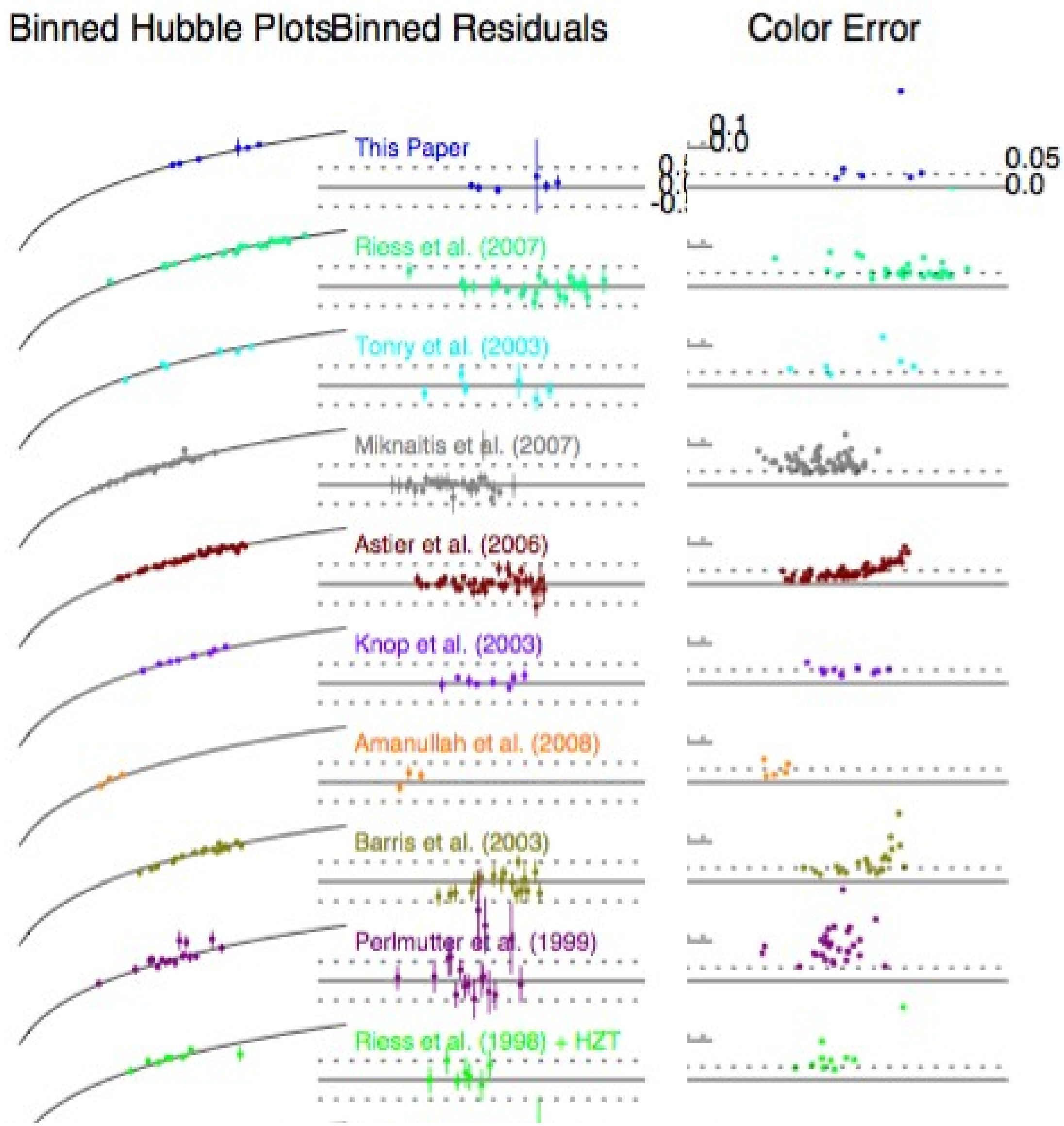
Things Worth Noting

- No survey covers the 0<z<1.7 redshift range
- Non-trivial effort goes into tying different datasets together
  - No guarantee of success
  - Cross-calibration uncertainties
- Low distance uncertainties for z>0.8 SNe from HST

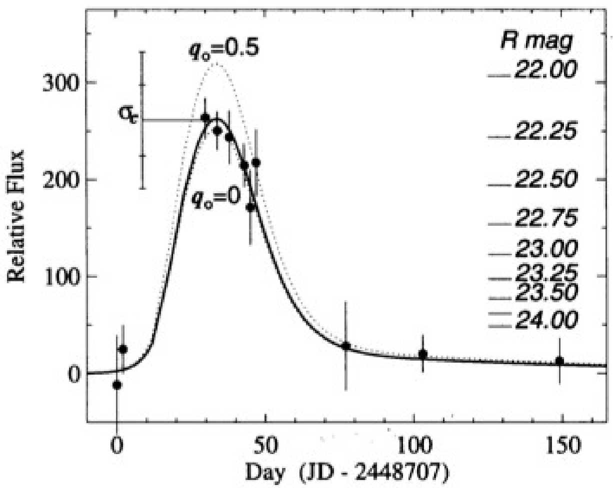


Things Worth Noting

- Color uncertainties drives distance uncertainties
- New data supersedes not supplements old data
  - Still data starved per SN

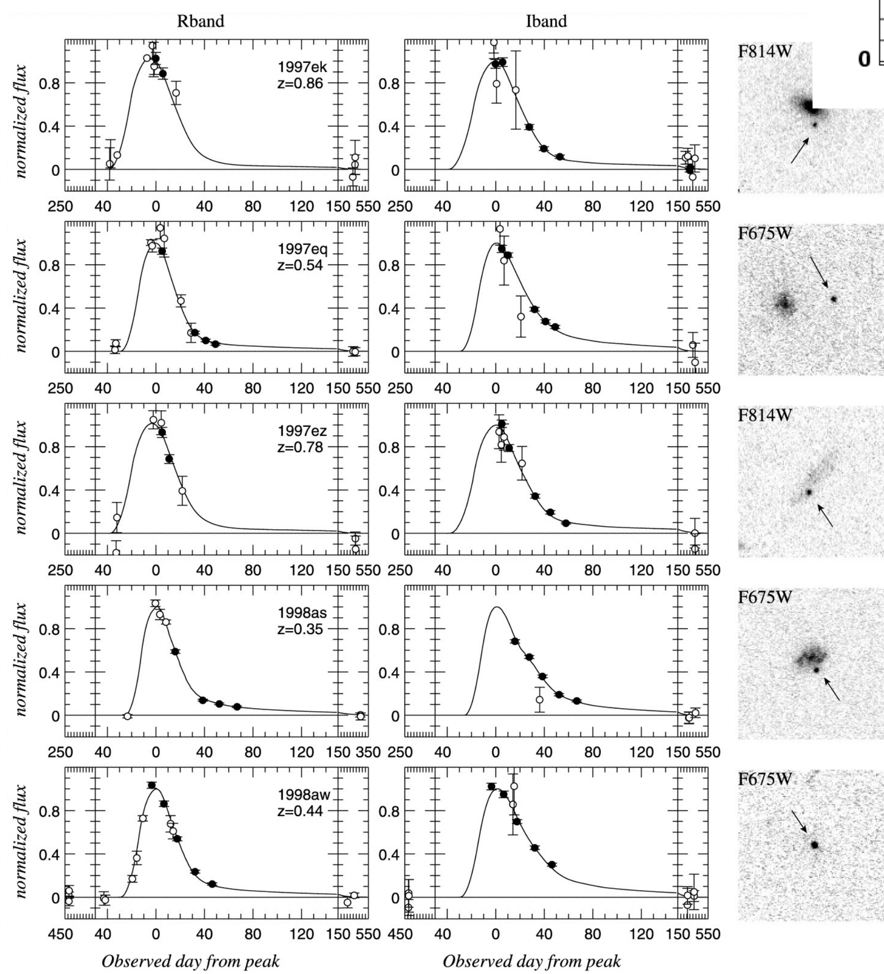


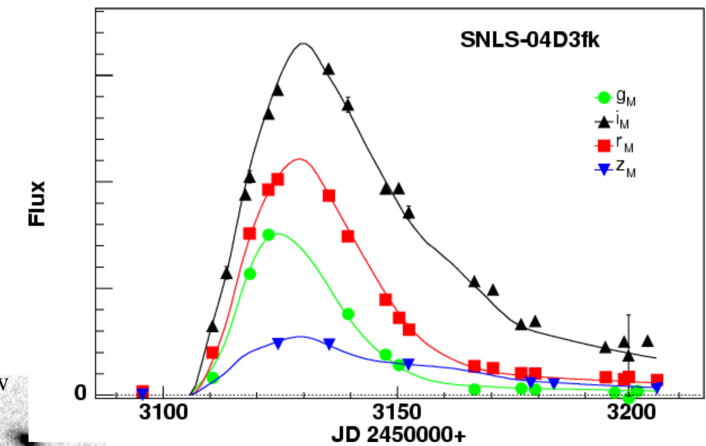
Improvement in Per SN Data



Perlmutter et al. (1995)

Knop et al. (2003)





Astier et al. (2006)

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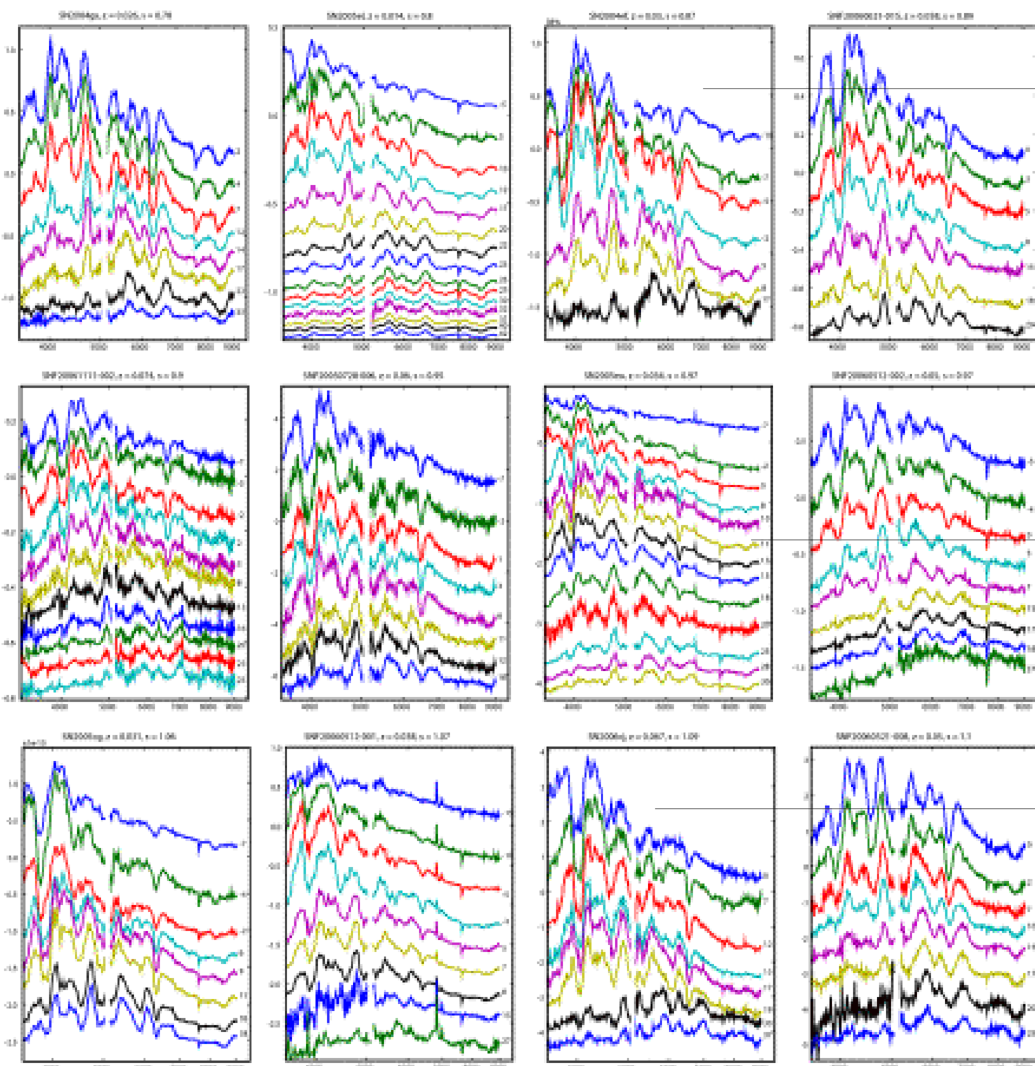
Modern Set Low-z

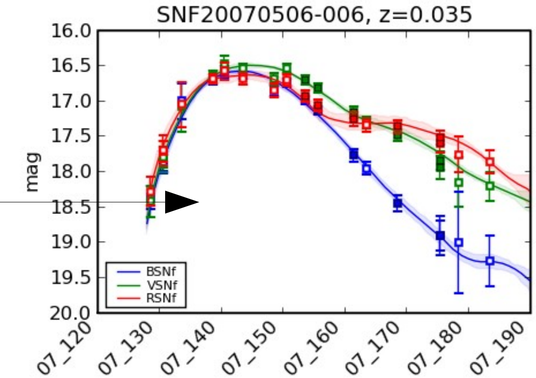
- SNFactory (Aldering et al.)
- SNIFS integral field unit at the UH 88”

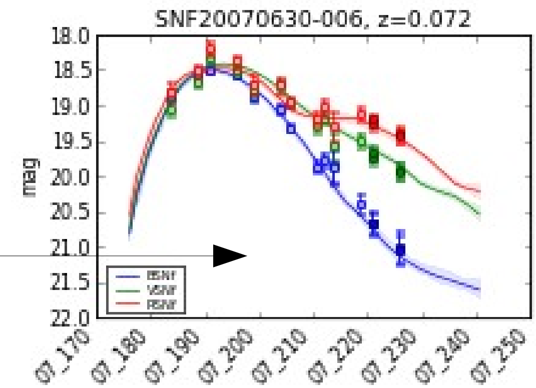
s = 0.90

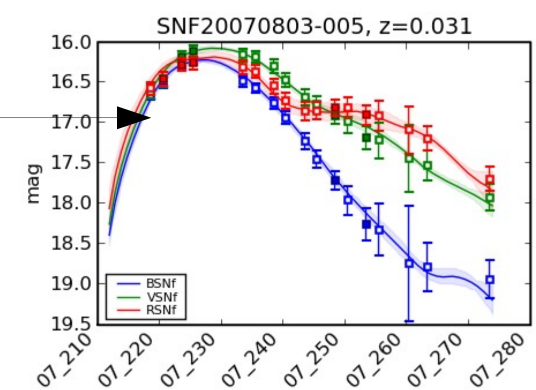
s = 1.00

s = 1.10





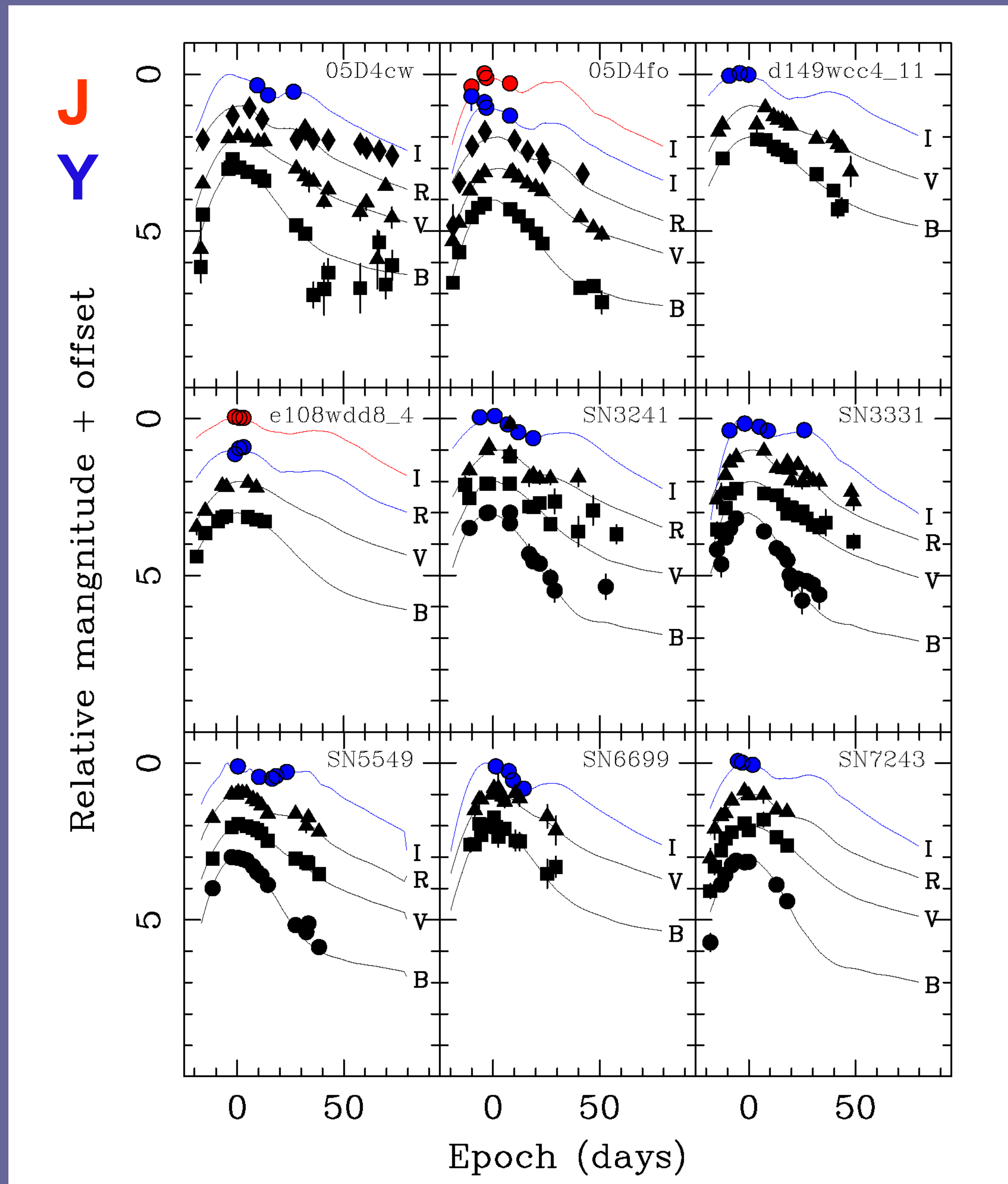




Carnegie Supernova Project: High z

I-band (YJ) photometry from Magellan

Optical BVR photometry from:
SNLS
ESSENCE
SDSS-II



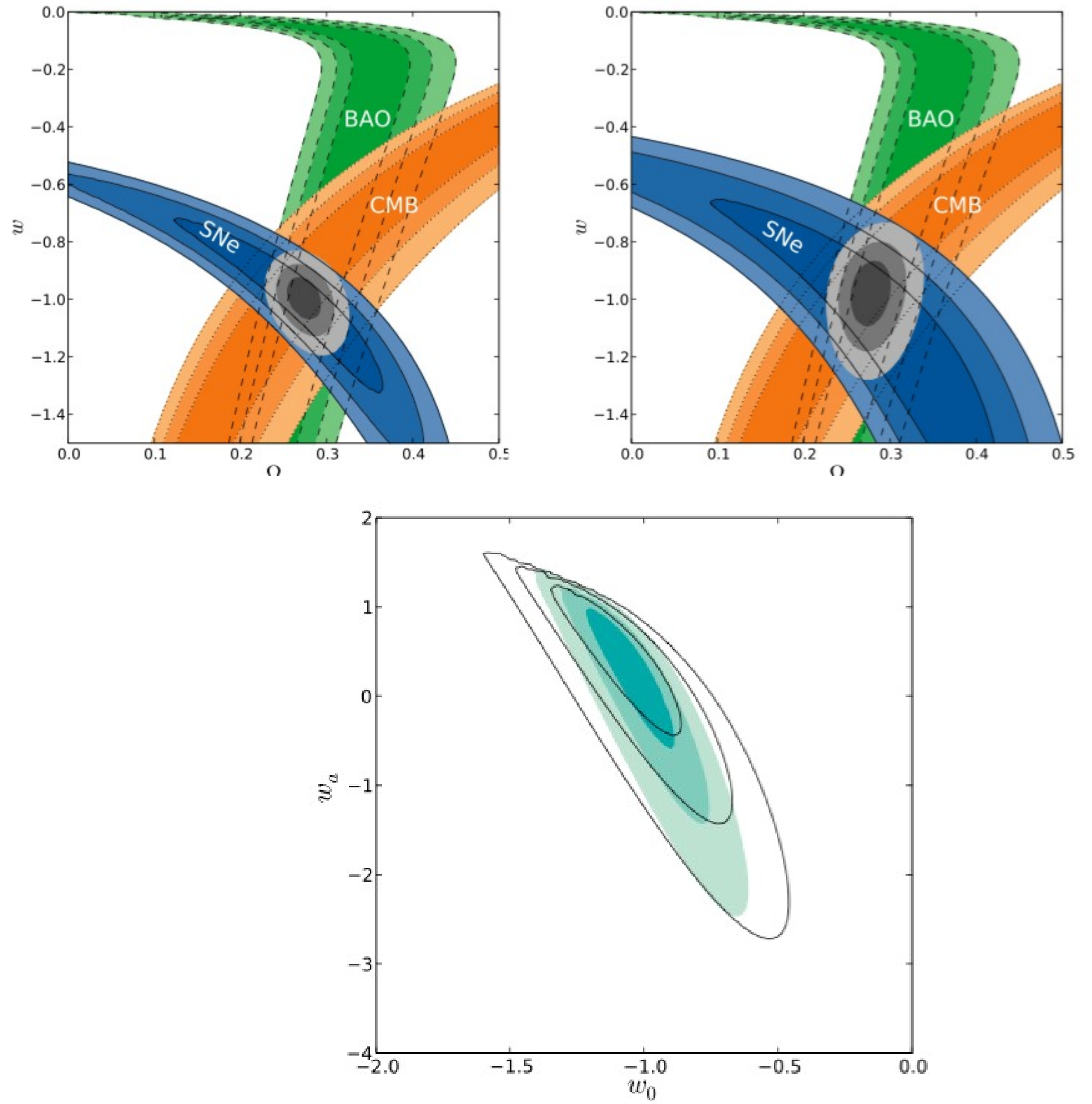
e.g., Magnitude uncertainties

<Y>	z
§ 0.03	0.1-0.3
§ 0.06	0.3-0.5
§ 0.08	0.5-0.7

Courtesy W. Freedman

Dark Energy Parameter Constraints

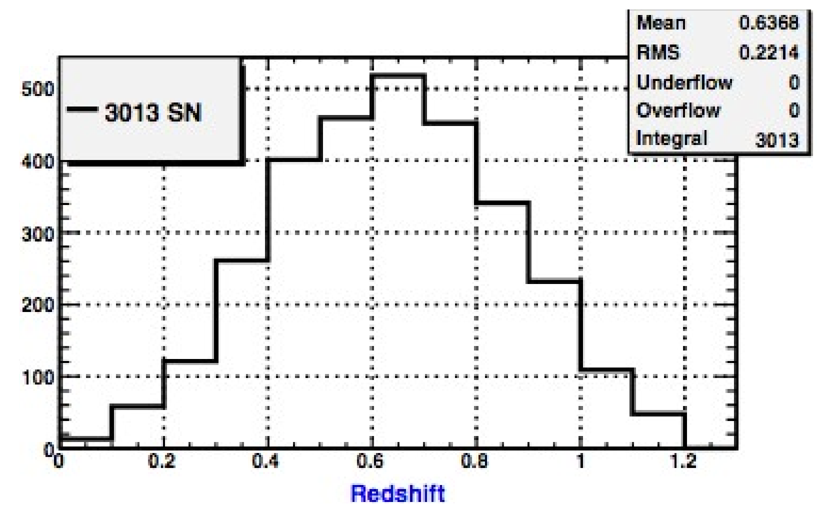
- BAO – Percival et al (2009)
- CMB - WMAP5
- DETF FoM
  - 5.5 without systematics
  - 3.3 with systematics DETF FoM
- Systematics Limited



Amanullah et al. (2009)

Dark Energy Survey

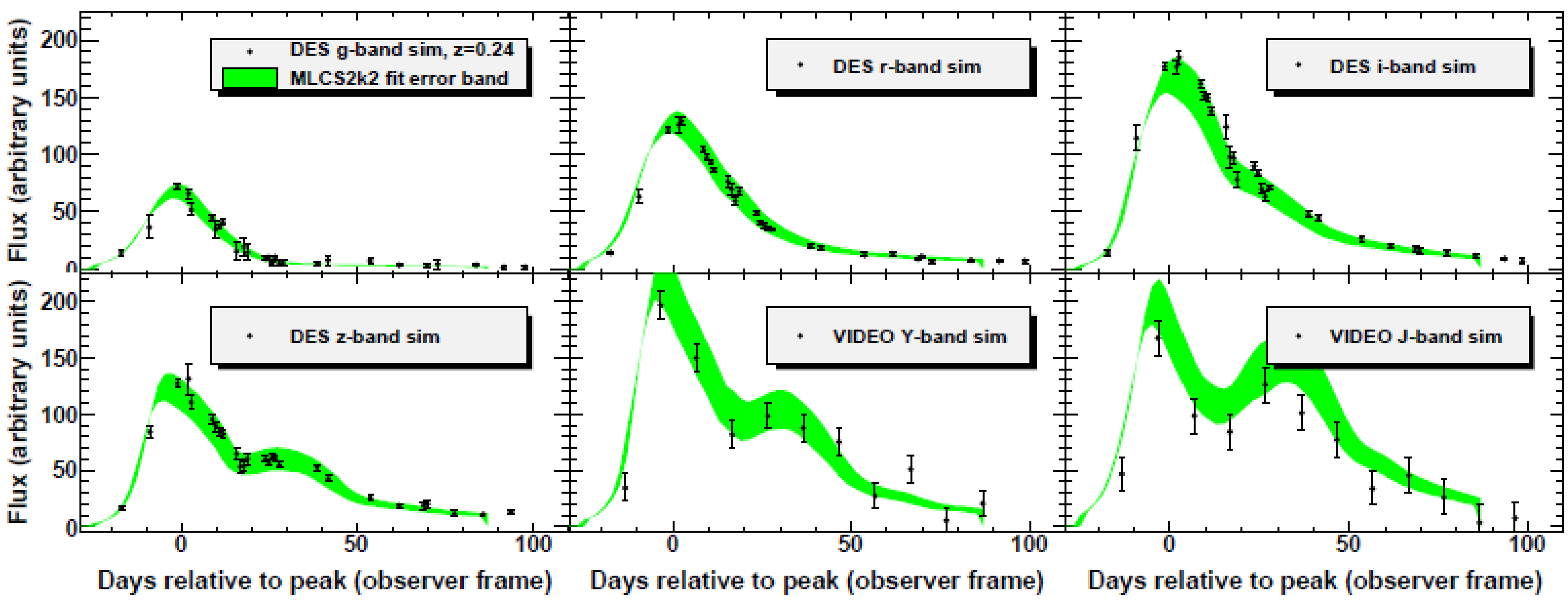
- CTIO 4-m
- ~3000 SNe Ia total in 5 years in 15 sd
- Important advance: thick fully-depleted CCD's give improved QE in the red
- Expected DETF FoM 150-180 (Stage II and Planck priors, no systematics)



From J. Bernstein

Dark Energy Survey + VIDEO

- Common fields with cadenced survey by DES and VIDEO (VISTA telescope)
- Expect 100 SNe with z<0.3



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From J. Bernstein

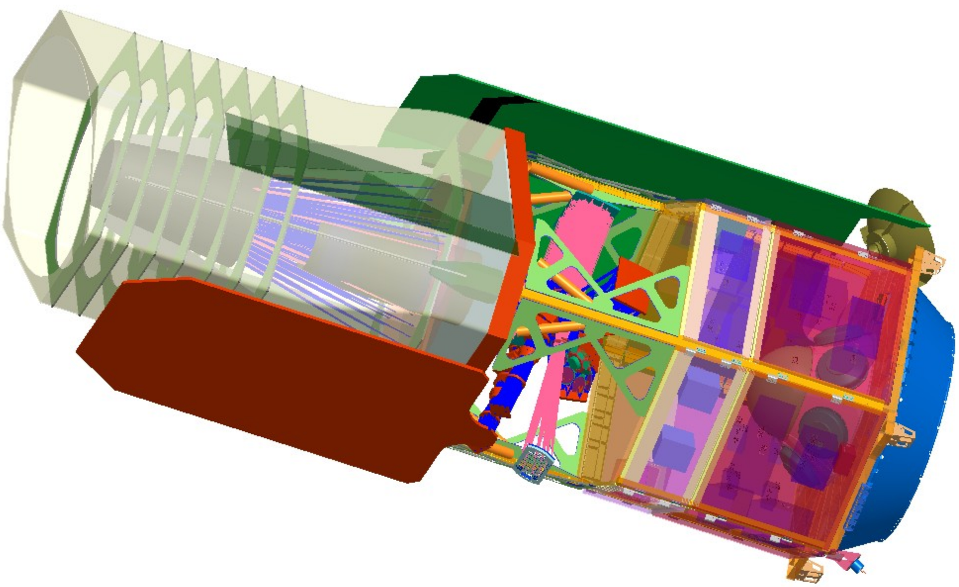
Where are we stuck today?

- SNe at different redshifts observed in different restframe wavelengths
  - Rest-frame UV and little optical of high-z SNe matches poorly with low-z data
- Multiple colors and broad wavelength coverage
  - Goal of CSP but small statistics, limited z range
- Intrinsic color vs dust
- Difficulties in getting z>0.8 from ground observatories

Where are we stuck today?

- HST collects z>0.8 SNe slowly
  - Spectroscopy of HST-discoveries
- Instrumental and absolute flux calibration
- Undiscerned independent indicators of SN absolute magnitude that may evolve with redshift

Joint Dark Energy Mission: Interim Science Working Group



http://jdem.gsfc.nasa.gov

Co-Chairs
Charles Baltay, Yale U.
Warren Moos, Johns Hopkins U.

Members
Dominic Benford, GSFC
Gary Bernstein, U.Penn.
Wendy Freedman, Carnegie Obs.
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Sangeeta Malhotra, ASU
Nikhil Padmanabhan, Yale U.
Jason Rhodes, JPL
Greg Tarle, U.Michigan

Ex-Officio Members
Neil Gehrels, GSFC
Michael Levi, LBNL

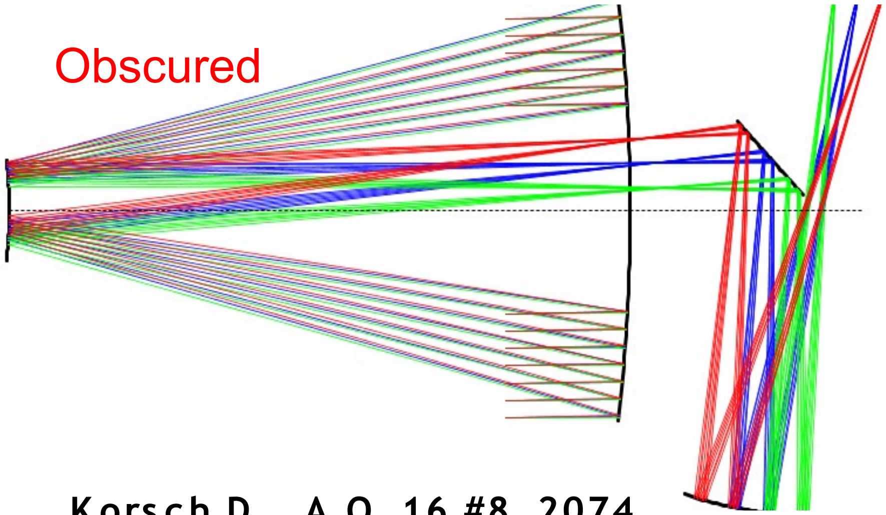
Our Challenge

- Develop JDEM designs that fit within a hard fiscal constraint of 650M$ (FY09) + launch
- ISWG presented two options to headquarters
  - SN+BAO fit within constraint
  - SN+WL+BAO doesn't quite fit (yet? work ongoing) but better dark energy science
- Attempt to derive an “optimal” SN Ia cosmology program while facing small telescope aperture, small number of detectors, restricted number of filters, incompatible platescale requirements

Obscured vs Unobscured TMA's

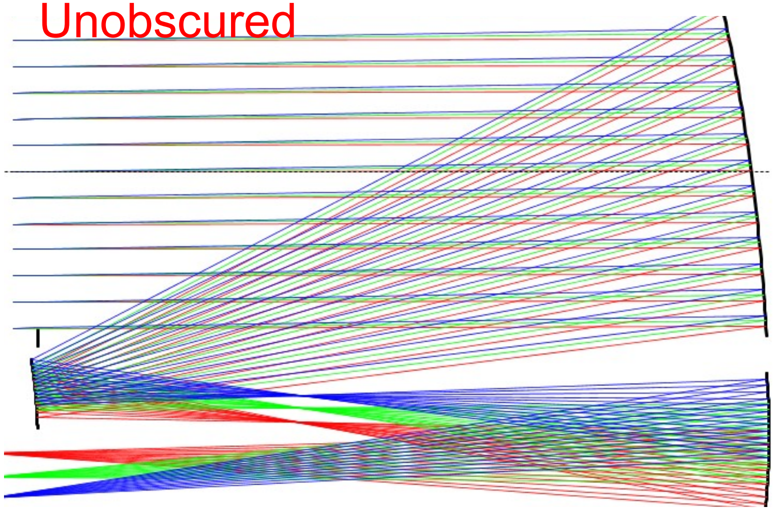
- For the same cost, a smaller-aperture unobscured telescope outperforms a larger-aperture obscured telescope
- A large secondary is required to provide the large field of view

Obscured



Korsch,D., A.O. 16 #8, 2074 (1977)

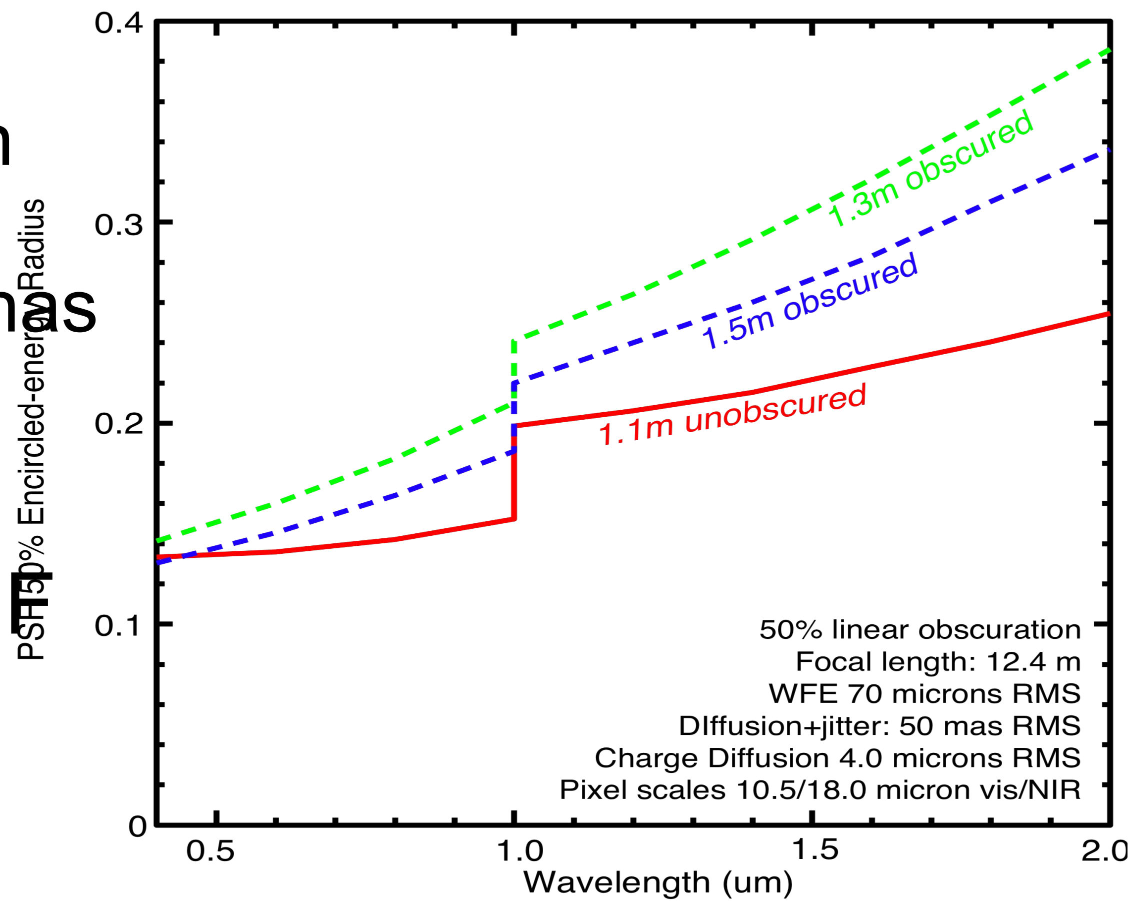
Unobscured



Cook,L.G., Proc.SPIE v.183 (1979)

A Sharper PSF

- Secondary Mirror
  - Blocks a significant fraction of light
  - Broadens the diffraction pattern: smaller unobscured telescope has a sharper PSF
- Leads to better shape measurements and PSF photometry
- Plotted is the 50% Encircled Energy Radius for the PSF



A “New” SN Ia Approach

- Wide-field imager for supernova search and discovery
  - Compatibility with imagers required for either BAO and WL: small number of filters, spatial resolution relatively unimportant
- IFU (slit) spectrograph for supernova light curves
  - Supernovae over a broad redshift range observed in common restframe with wavelength multiplex
  - Critical sampling achieved independent of the imager platescale

Benefits

- SN program easily added to a BAO and/or WL program
  - An “inexpensive” IFU (slit) spectrometer
  - Extra mission lifetime
- Direct flux calibration
- Targeted survey more efficient than a rolling survey
  - Given the telescope aperture and field of view JDEM offers minimal multiplex advantage

Following up “easier” SNe

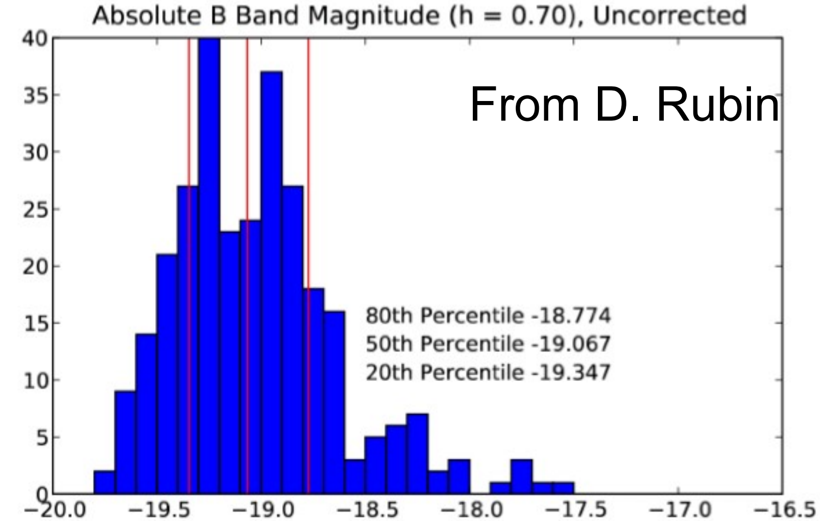
- A large search survey square-degree – years overproduces SN Ia discoveries
- Targeting “easier to observe” supernovae saves follow-up time
  - Brighter supernovae
  - Fainter host-galaxy surface-brightness
- Saves in total time as follow-up requires more time than search

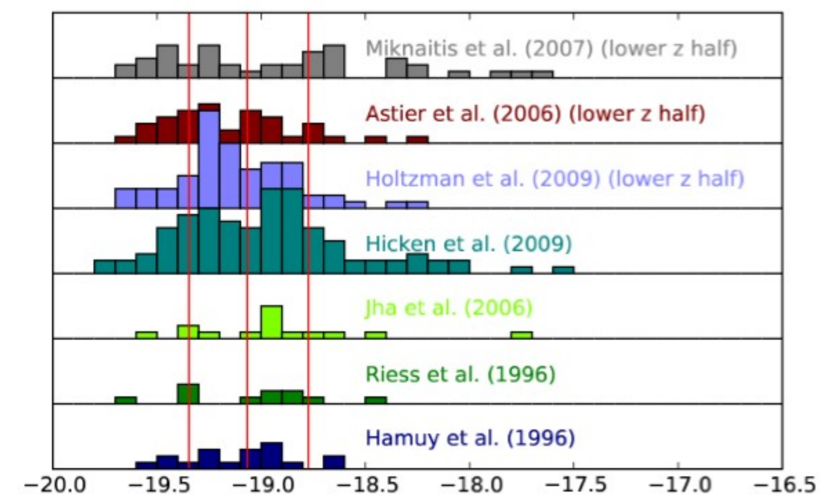
"Observed" Absolute SN Ia Magnitudes

- When background limited, the average 1-SN targeted exposure time corresponds to magnitude

$$2.5 \log \sqrt{< 10^{2M/2.5} >}$$

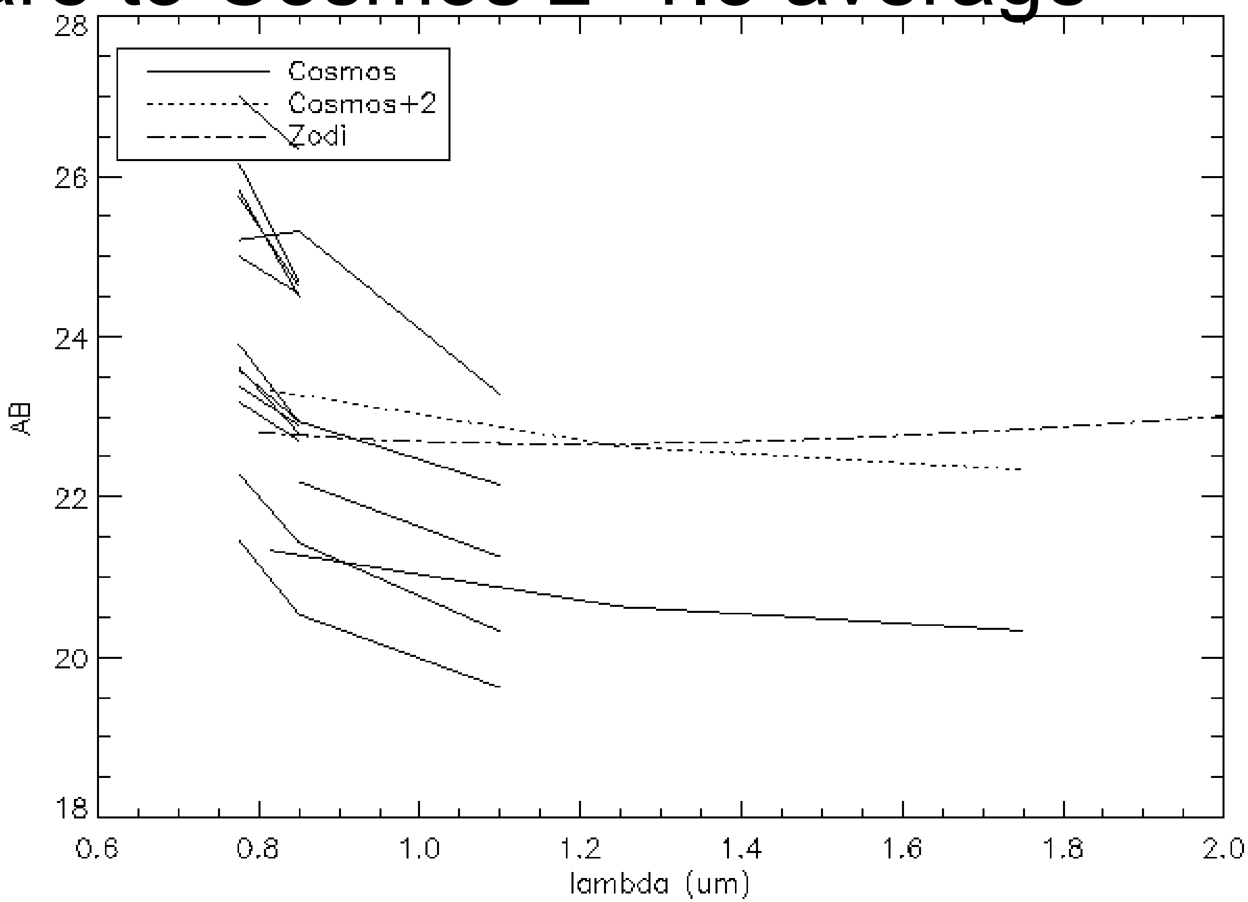
- Average over the 60% brightest SNe is -19.231
- Compare to 60%-ile -18.96 required for rolling surveys and search





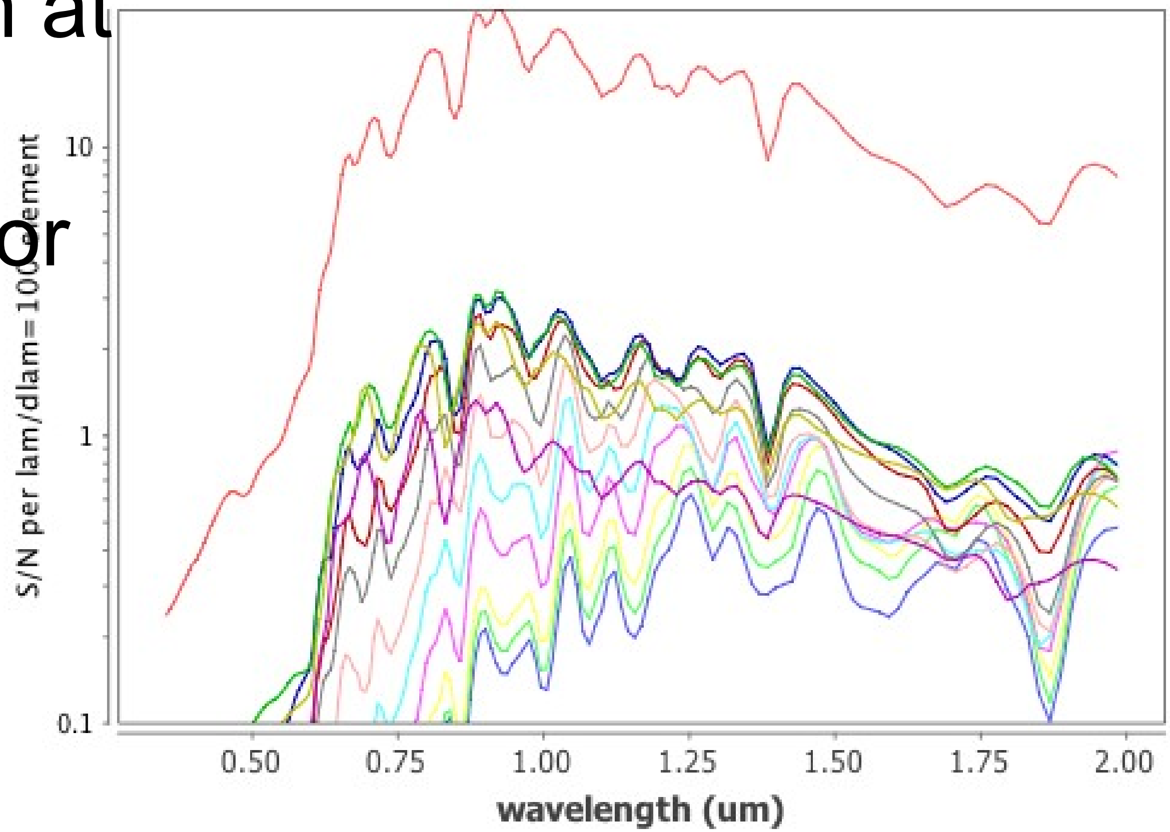
Host-Galaxy SB : <z>=1.3

- Plot SB at the position of 1.2<z<1.4 SNe as measured by HST
- Compare to Cosmos z=1.3 average



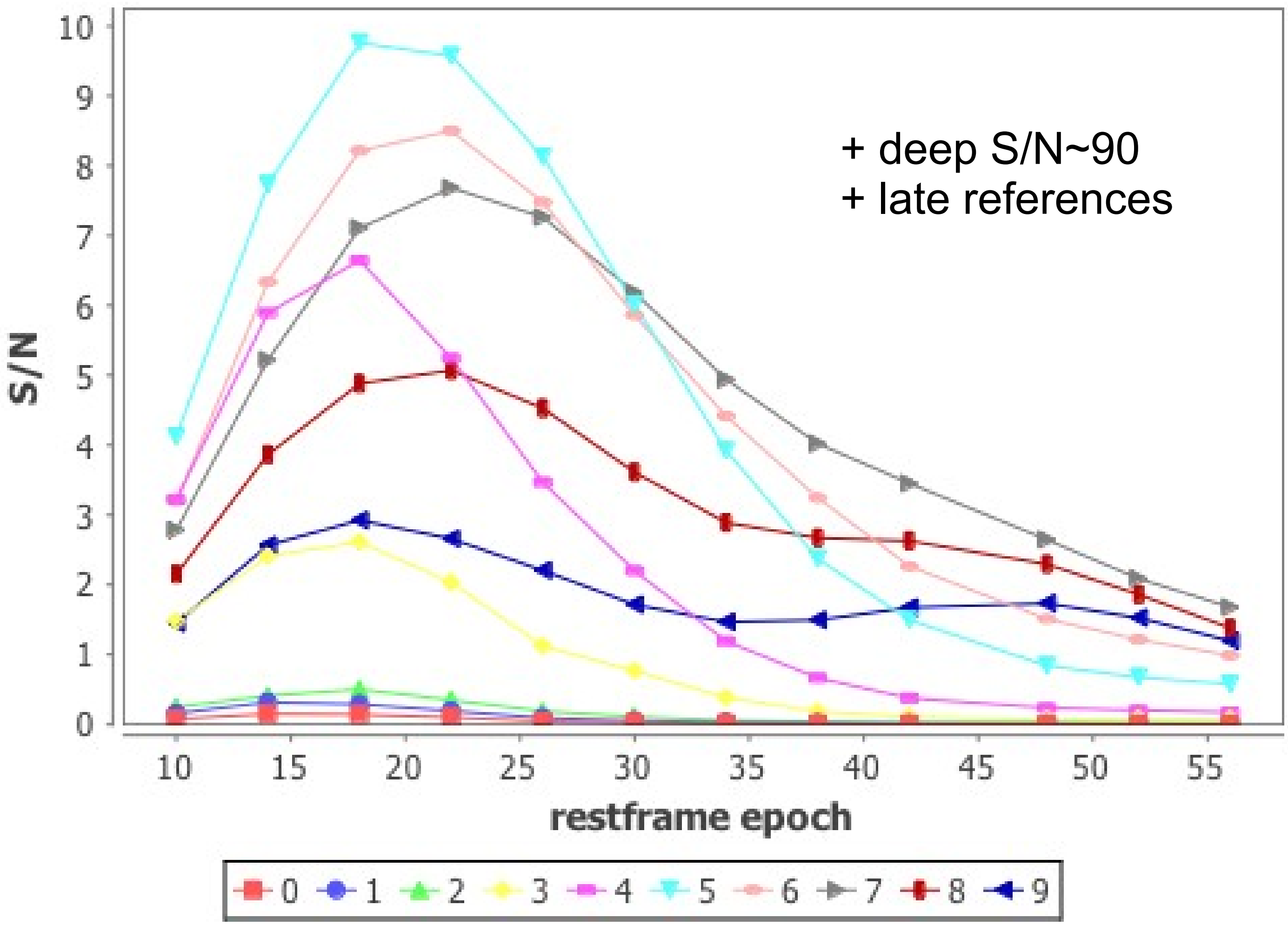
JDEM SN Ia Data Quality: Example

- SN at z=1.3
- One deep spectrum at peak for subtyping
- Shallower spectra for “light curves”
  - 4-day restframe cadence
  - [-10,50] rest-frame epochs
  - 4 deep references



Synthetic Photometry

- Light curves in 10 independent synthetic bands



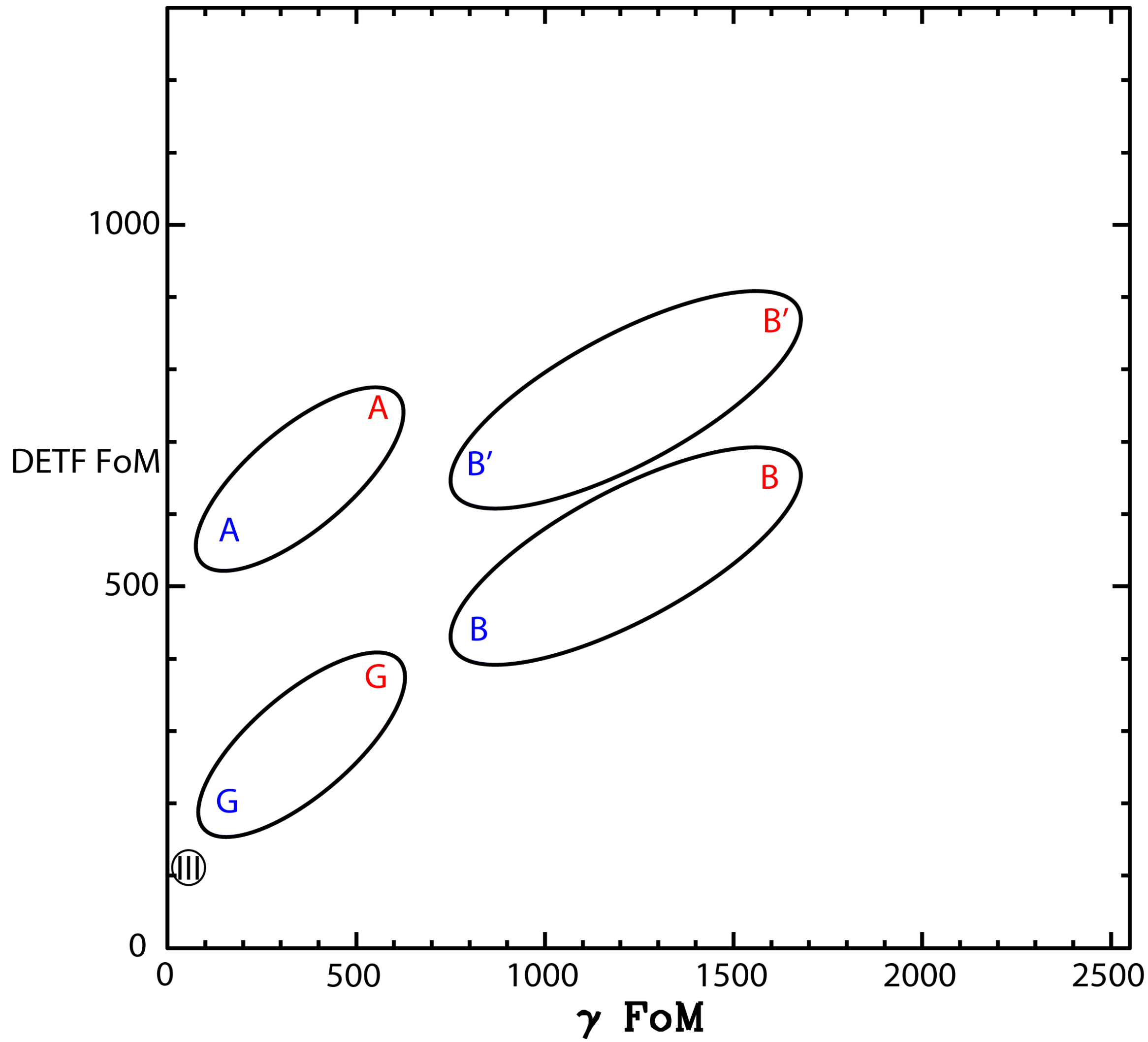
SN Survey Yield: Example

- WL requires a larger and high-resolution imager than BAO
  - Affects the search, SN spectroscopic followup same
- SN+BAO – optimized missions
  - IFU 133 SNe/0.1 bin 0.3<z<1.3
  - Slit 108 SNe/0.1 bin 0.3<z<1.3
- SN+BAO+WL – optimized mission
  - IFU 138 SNe/0.1 bin 0.3<z<1.3
  - Slit 111 SNe/0.1 bin 0.3<z<1.3
- Can trade numbers for redshift depth

BAO and WL Performance

- BAO – Slitless spectroscopy
  - 16000 square degrees in 1.5 yrs
  - $1.3<z<2.0$
  - Depth of 2×10^{-16} ergs cm^{-2} s^{-1}, redshifts for 60 million galaxies
  - Redshift uncertainty $0.001(1+z)$
- WL – shape, NIR photo-z, photo-z calib surveys
  - 10000 square degrees
  - 30 galaxies $arcmin^{-2}$
  - 100000 photo-z calibration spectra
  - (needs ground optical for photo-z)

Figure of Merit Summary



III is FoMSWG Stage III FoM

A and B stand for Designs A and B
G is for Ground Based

A is WL and SNe
- B is WL and BAO

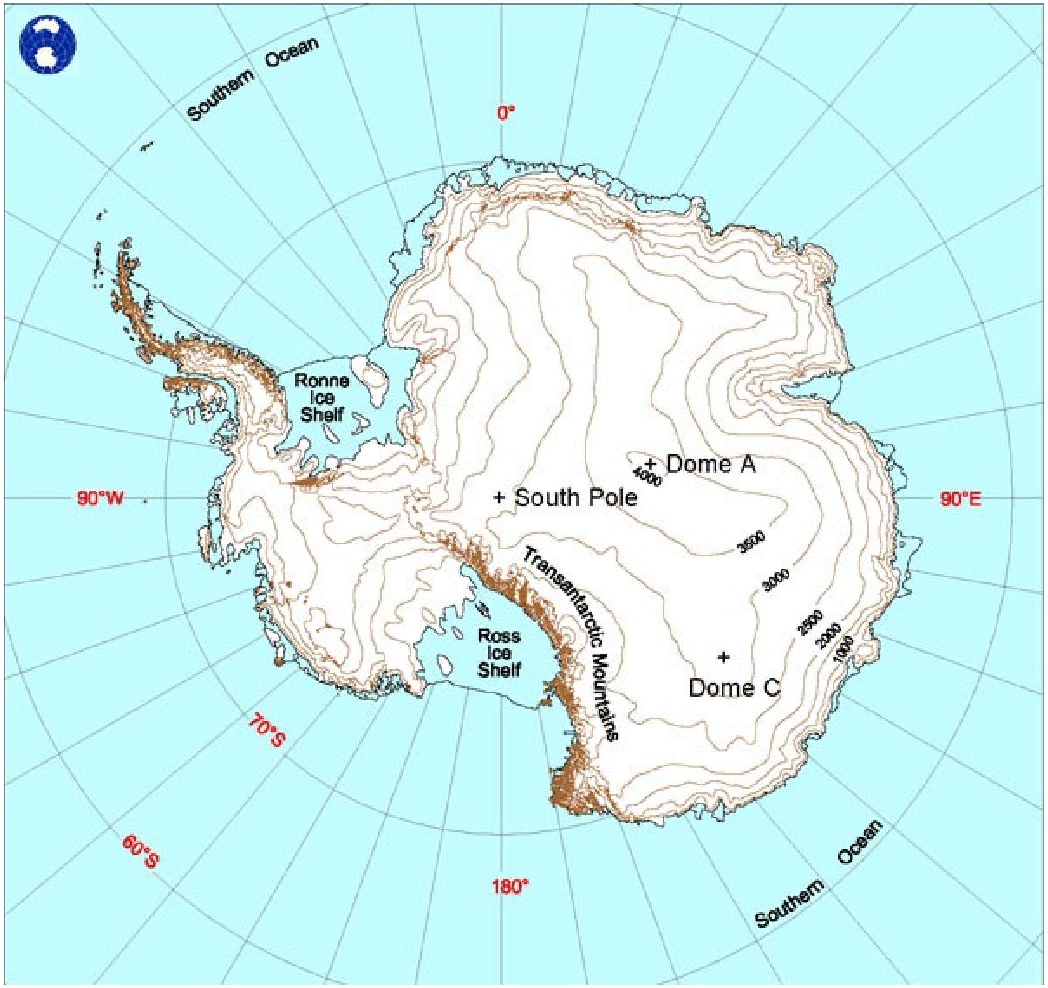
B′ is WL, BAO, and SNe

Blue for minimal ground program
Stage III + Double DES + u band

Red is for a maximal Stage IV Ground program including BigBOSS(24,000 sq deg) and LSST

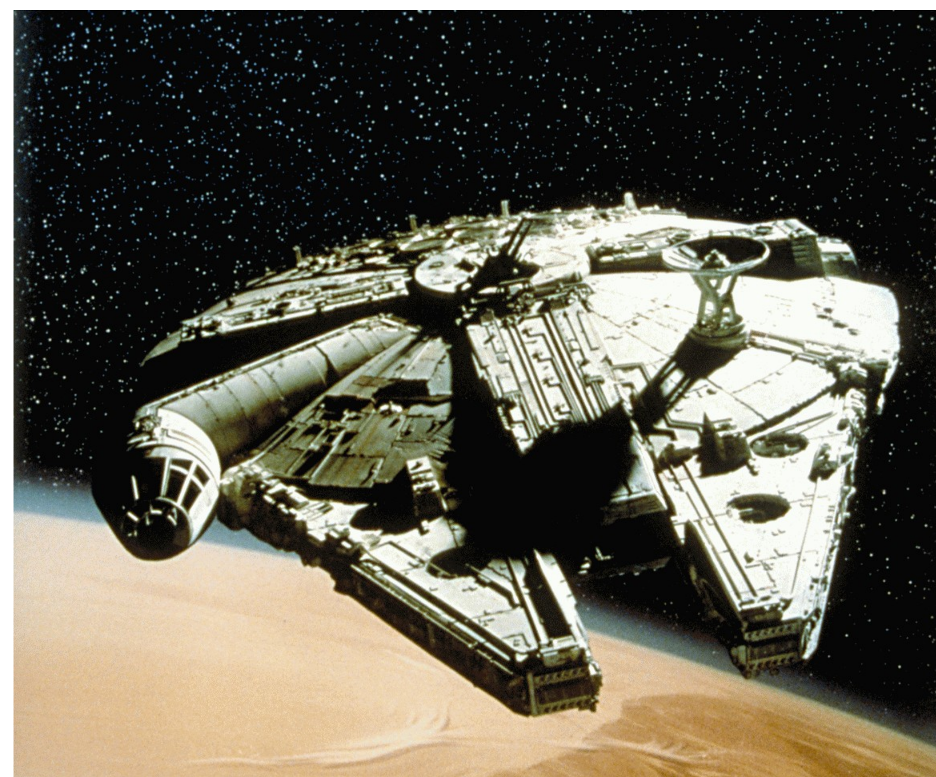
Dome A

- Highest plateau in Antarctica at 4093m
- 1200 km from nearest coastal stations 1100 km from the South Pole
- Summer station exists, winter station planned
- PLATeau Observatory (PLATO) actively taking data



Dome A vs Space

	Dome A	Space
Access	20-day tractor traverse	100 days on spacecraft to L2, one-way trip



Dome A vs Space

	Dome A	Space
Temperature	204K	3K

Dome A vs Space

Dome A

Space

Scary Critters

Interesting Dome A Characteristics

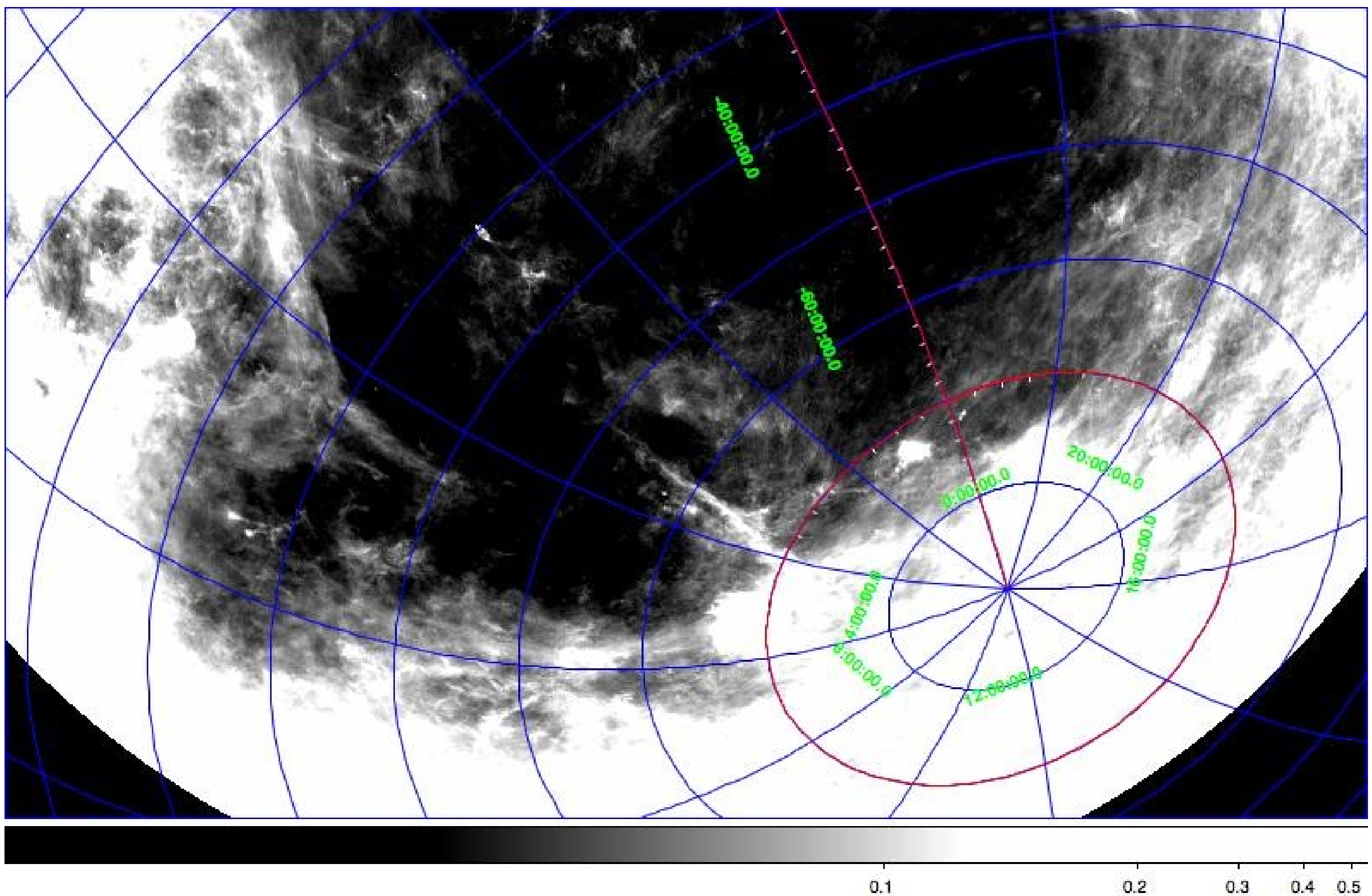
- Boundary layer <20-m, above which...
- $0.3(\lambda/0.5\mu m)^{-0.2}$" median free seeing expected based on Dome C, first PLATO measurements
- Kdark (2.27-2.45 μm) 0.2" seeing and faint $100\mu Jy/arcsec^2$ sky brightness
- Precipitable water vapor column 141 microns (over an order of mag less than Mauna Kea)
- Observe every "day"

Interesting Dome A Characteristics

- Observe every “day”
- Observatory being established by China
  - AST3: 3 0.5-m telescopes, 9 sd imager next summer
  - 2.5-m telescope pathfinder being developed

Available Survey Field

- 9000 square degrees χ<2, E(B-V)<0.2



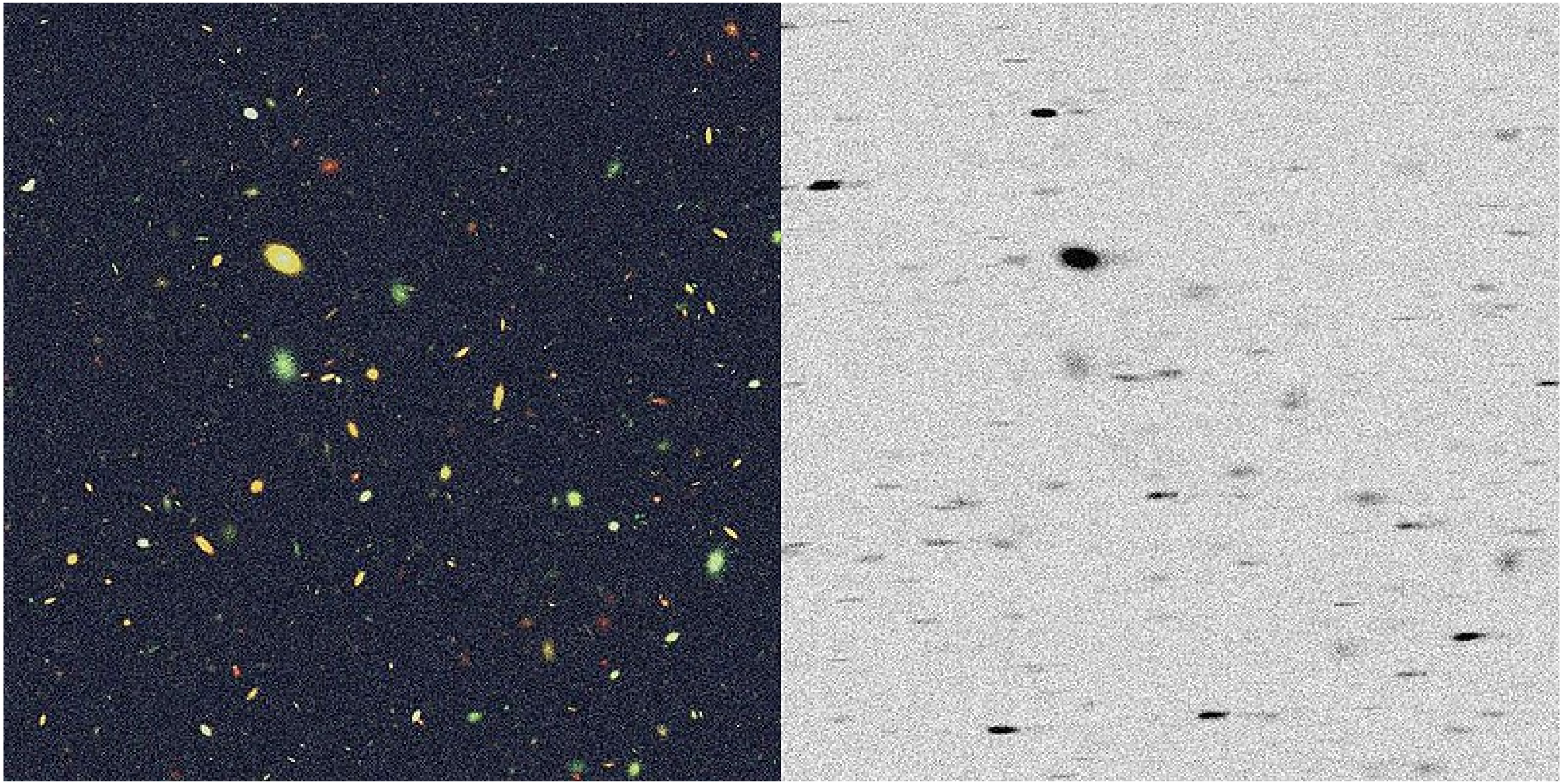
Schlegel, Finkbeiner, Davis map of Galactic dust

Site Characteristics to Cosmology

- BAO/Clustering – A window of opportunity from (2.0?) 2.5<z<<2.8
- SNe
  - Nearby SN survey possible with existing and anticipated telescopes
    - No gaps in the time series for template building
  - High-z SN survey: Not efficient (but possible?)
  - High-z SN search: Possible out to z=3
- Weak Lensing
  - 0.3” (optical), 0.2” (Kdark) seeing

Slitless Spectroscopy

- Spectroscopy of a wide field-of-view with higher sky background and source confusion



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SLIM Simulation of a WFC grism observation

Slitless Spectroscopy At Dome A

- Dome A has unique properties that can take advantage of slitless spectroscopy
  - Excellent seeing means source occupies small solid angle
    - Low-redshift supernovae can be source-noise dominated
  - Low sky background in Kdark
    - Detection of high-redshift emission-line galaxies

Kdark Slitless Spectroscopy

- Interesting Signals – Emission-line galaxies and quasars
  - Current ground-based telescopes (Gemini + NIRI) go as deep as 10^{-16} erg/cm^2/s
  - BigBOSS targeting 3 x 10^{-17} erg/cm^2/s
- 100μJy/arcsec^2 = 5.2 x 10^{-18} erg/cm^2/s/Å/arcsec^2 at 2.4 μm
- Redshifts
  - Halpha 2.5<z<2.8
  - [OIII] 3.5<z<3.9
  - [OII] 5.1<z<5.6

Emission-Line Survey

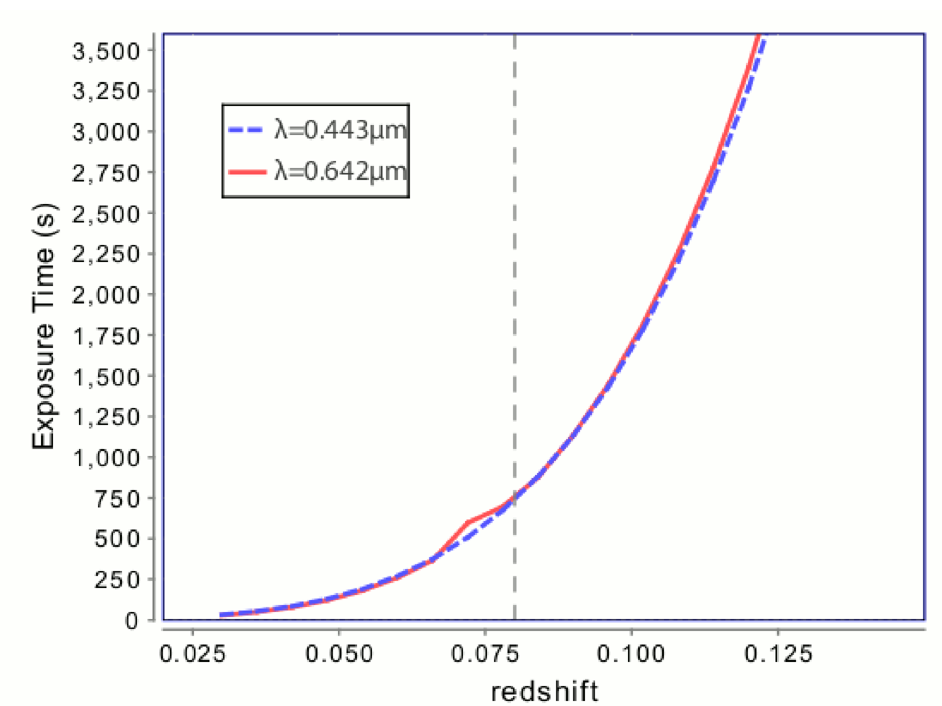
- Consider 2.5-m telescope with 60% throughput
- 0.4”x0.4” sources
- 10^{-17} erg/cm^2/s/Å flux limit
- 10^4 s to get S/N=5
- 8000 square degrees covered in 3 calendar years with a 2 square degree field-of-view

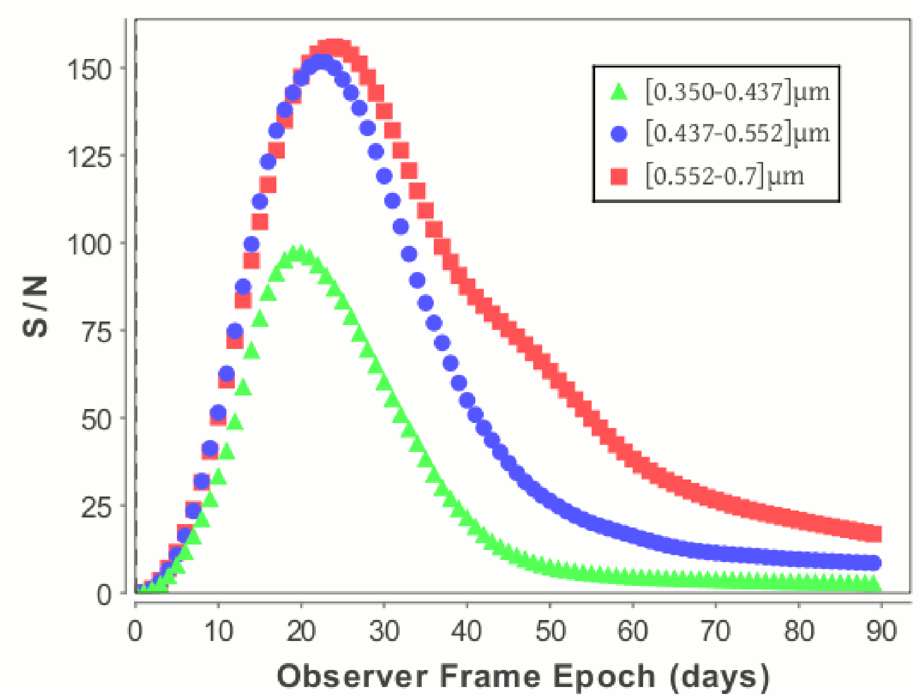
Emission-line Survey Science

- BAO at redshifts beyond BigBOSS and JDEM
  - Too thin redshift? Expand wavelength window?
- Measurement of P(z)
- High-z quasars
- Population 3 stars
- Galaxy and star-formation history
- ???

Low-z SN Slitless Spectroscopy

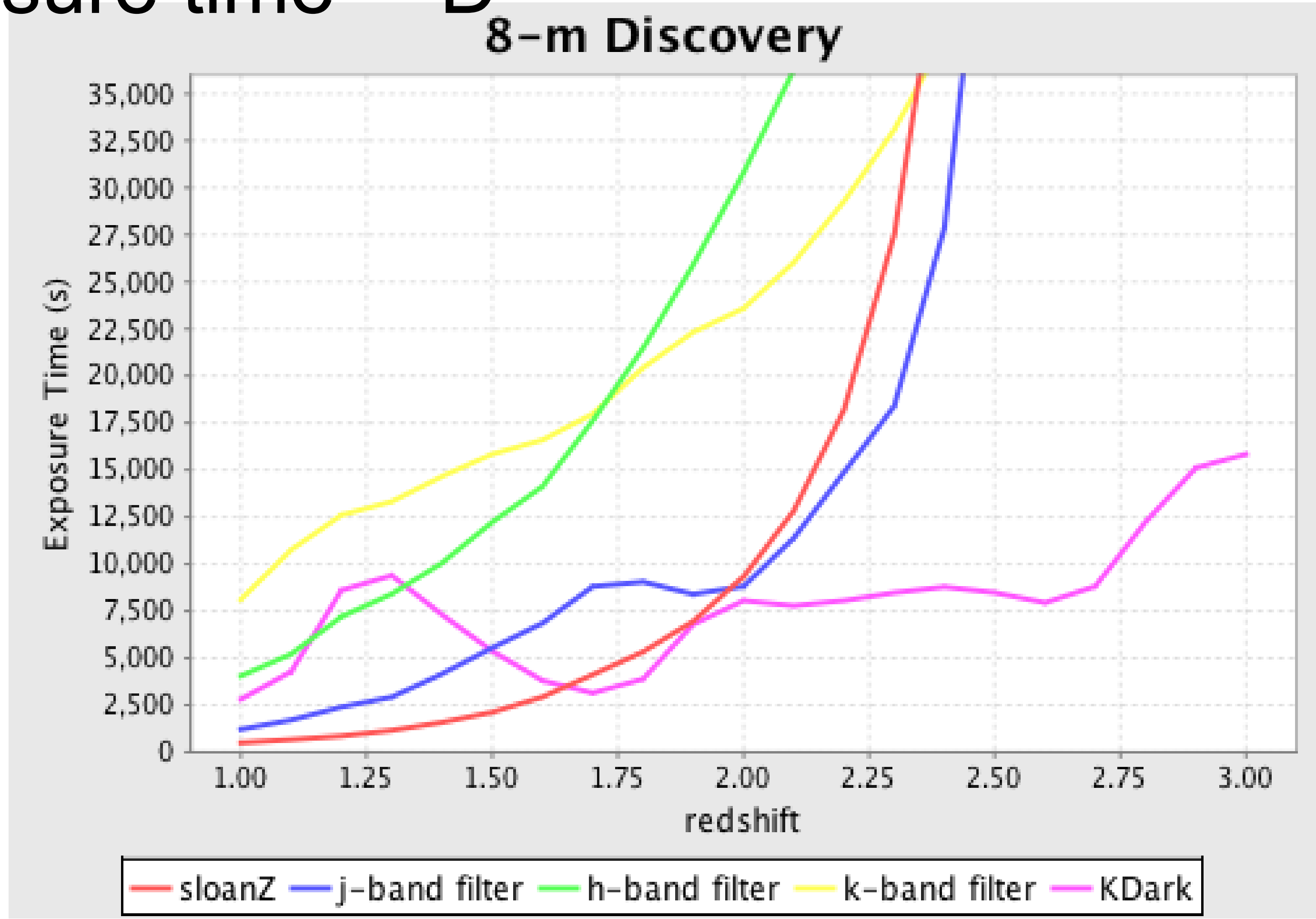
- 0.3” seeing allows small sky background for source-limited slitless spectroscopy
  - z=0.08 at peak source-noise dominated
- 1-m telescope can monitor available sky





High-z Search on an 8-m

- z=1.7, Z-band CCD, 3000s exposure
- 1.7<z<2.75, Kdark 8000s exposure
- Exposure time $\propto D^{-2}$



Conclusions

- SN Ia remain as one of the leading probes of the accelerating Universe and of dark energy
- New observatories with unique characteristics can open new windows for SN Ia cosmology
  - A 650M$ JDEM can produce worthy science and a little more money can give much more
  - Dome A has interesting characteristics, worth considering how they can be used to our advantage

Host-Galaxy Surface Brightness

- Measured surface-brightness at SN positions from HST measurements
- F775W and F850LP values are well-determined (N. Suzuki), F110W has known problem with the zeropoint (L. Faccioli, D. Rubin)
- Compared to Cosmos average (S. Kent)

Targeted Survey

- Wide-field imaging SN search
  - Deterministic monitoring of survey fields for early identification of rising SN Ia light curves
- Triggered spectroscopic (IFU or Slit) followup
  - Spectrum at peak for SN Ia subclasification
  - Spectra covering each SN's time evolution to provide “multi-band” light curves
  - Spectra also provide redshift